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OPERATING CHARACTERISTICS OF A 45-DEG-SLANT, SEGMENTED WALL, MAGNETOHYDRODYNAMIC GENERATOR CHANNEL UNDER NO-POWER CONDITIONS

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ARO, Inc.

April 1970

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ROCKET TEST FACILITY
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OPERATING CHARACTERISTICS OF A 45-DEG-SLANT, SEGMENTED WALL, MAGNETOHYDRODYNAMIC GENERATOR CHANNEL UNDER NO-POWER CONDITIONS

M. A. Nelius
ARO, Inc.

FOREWORD

The test program reported herein was conducted at the request of the Air Force Aero-Propulsion Laboratory (AFAPL), Air Force Systems Command (AFSC), Wright-Patterson Air Force Base, Ohio, for Chrysler Corporation, Space Division, Huntsville Operations, under Program Element 62402F, Project 3145.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. The test was conducted between September 24 and October 7, 1969, in Propulsion Research Area (R-2C-4) of the Rocket Test Facility (RTF) under ARO Project Number RW0903, and the manuscript was submitted for publication on February 12, 1970.

Information in this report is embargoed under the Department of State International Traffic in Arms Regulations. This report may be released to foreign governments by departments or agencies of the U.S. Government subject to approval of the Air Force Aero-Propulsion Laboratory (APIE-2), or higher authority within the Department of the Air Force. Private individuals or firms require a Department of State export license.

This technical report has been reviewed and is approved.

Walter C. Knapp
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ABSTRACT

A test program was conducted to determine the aerodynamic and thermal operating characteristics of a 45-deg slant-wall, magnetohydrodynamic generator channel under no-power conditions. The generator channel was 32.3 in. long with an inside diameter of 2.0 in. at the inlet, diverging to 4.9 in. at the channel exit. The plasma was provided by a liquid oxygen/JP-4 combustor having a nominal nozzle exit Mach number of 1.55. A solution of cesium carbonate dissolved in water was injected into the combustor to produce a high ion concentration in the exhaust stream. Nominal combustor operating conditions were as follows: chamber pressure, 220 to 275 psia; oxidizer-to-fuel ratio, 2.5 to 4.6; cesium concentration, 0.0 to 8 percent of total flow. Firing durations ranged from 4.6 to 7.6 sec. Tabulations of combustor operating conditions and a discussion of channel operating characteristics are presented.

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SECTION I
INTRODUCTION

Development of an airborne, magnetohydrodynamic (MHD) generator system was initiated to energize a high intensity light source (Refs. 1 and 2). The MHD generator is designed to operate at power densities on the order of 125 Mw/m^3 and to provide a total power output of 1 Mw.

The MHD generator system consists of a combustor system which provides an electrically conducting gas at specified conditions to the inlet of an MHD channel located between the poles of a liquid-helium-cooled, superconducting magnet designed to produce field strengths on the order of 70 kilogauss. A seeding agent having a low ionization potential is injected into the combustion chamber to increase the electrical conductivity of the combustion products. The same physical principles are involved in an MHD generator as in a conventional generator except that conducting gases replace the metallic conductors of the rotor.

Generator components which have thus far emerged from the MHD generator development program include a first-generation combustor system (Ref. 1), an improved combustor system which incorporates a refined nozzle geometry and more versatile injector configuration (Ref. 3), and a 45-deg slant-wall, heat-sink, MHD channel which is composed of 105 copper segments (Ref. 1). Testing was performed with the first-generation combustor coupled to the heat-sink, MHD channel to determine the system operating characteristics under no-power conditions (Ref. 4).

The program reported herein was conducted to determine the operating characteristics of the heat-sink, MHD channel (modified slightly from the configuration reported in Ref. 4) when coupled to the improved combustor. Specific test objectives were to determine (1) channel static pressure distribution, (2) channel temperature variation, and (3) channel structural operating characteristics during combustor firings accomplished with variations in fuel-oxidizer ratio, chamber pressure, and seed rate.

The program was conducted in Propulsion Research Area (R-2C-4) of the Rocket Test Facility (RTF). The RTF personnel were responsible for the design and fabrication of the combustor and associated propellant, instrumentation, and exhaust systems. The instrumented MHD channel assembly was supplied by the Chrysler Corporation, Space Division,

Huntsville Operations. Testing was performed in accordance with the technical direction provided by Chrysler.

This report summarizes the results from seven firings having burn durations ranging to 7.6 sec. Channel operating characteristics, static pressure distribution, and temperature measurements are discussed.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article consisted of a combustor and a 45-deg-slant, segmented wall, MHD generator channel and diffuser. These components are described in detail in the sections to follow.

2.1.1 MHD Generator Channel Assembly

The MHD generator channel assembly (Fig. 1, Appendix I) consists of a 3.6-in.-long forward transition element, a 32.3-in.-long segmented MHD channel, and a 24.0-in.-long constant area diffuser. The flow passage of the assembly diverges from an inlet diameter of 2.0 in. at a 1-deg half-angle for an axial distance of 5.9 in. The divergence half-angle, beginning 5.9 in. from the channel inlet and continuing to the inlet of the 4.9 in. diameter diffuser, is 2.5 deg.

The segmented MHD channel is assembled from 103 individually insulated wall segments inclined forward at 45 deg to the channel axis to form a laminate array. The segments are fabricated from 0.1875-in.-thick electrolytic, tough pitch (ETP) copper plate. Electrical insulation between channel segments is provided by a 0.032-in.-thick inorganic Isomica® plate. Each segment is attached to adjacent segments by ceramic-insulated stainless steel screws (16 screws per segment for the first 25 segments and 8 screws per segment for the remainder).

Transition from the combustor nozzle exit to the MHD channel entrance is effected by the unsegmented forward transition element made of ETP copper. The diffuser is a constant area, unsegmented, ETP copper duct with an outside diameter of 6.1 in. and a wall thickness of 0.6 in.

The channel, forward transition element, diffuser, and associated pressure and temperature instrumentation lines (Fig. 1a) were delivered to the Rocket Test Facility as an integral unit.

2.1.2 Combustor

Ionized gas is provided to the MHD generator channel by a water-cooled, liquid oxygen (LO_2)/JP-4 combustor (Fig. 2). Details of combustor design considerations and operating characteristics are presented in Ref. 3. The combustor injector assembly (Fig. 2) incorporated provisions for injecting a seeding agent which consisted of a solution of 70-percent cesium carbonate (Cs_2CO_3) and 30-percent water (by weight) into the combustion chamber to provide a high ion concentration in the exhaust gases.

The combustor incorporates a contoured supersonic exhaust nozzle that diverges from a throat diameter of 1.777 in. to a diameter of 1.983 in. at the exit, providing an area ratio of 1.25 and a nominal exit Mach number of 1.55. The nozzle exit half-angle was 0 deg. A flange at the nozzle exit adapts the combustor to the forward transition element of the channel.

2.2 INSTALLATION

The combustor and the channel assembly were installed in Propulsion Research Area (R-2C-4). Photographs and a schematic of the installation are shown in Fig. 3. The combustor was mounted on a support stand and connected to the facility propellant and cooling systems. The combustor nozzle flange was aligned with, and bolted to, the forward flange of the channel. The channel diffuser extended through an asbestos slip-joint seal (Fig. 3b) at the forward bulkhead of a spray chamber containing one air spray ring and six water spray rings. The spray chamber was electrically insulated from ground through the use of insulated support pads and water lines. A 12-in. exhaust duct was bolted to the downstream end of the spray chamber to direct the cooled exhaust gases into the facility exhaust ducting to be discharged into the atmosphere.

A schematic of the propellant system is shown in Fig. 4. Combustor ignition was accomplished with a 0.25-lb_m charge of triethylborane (TEB) loaded in the downstream section of the secondary fuel line. The LO_2 was supplied from two 550-gal tanks pressurized with gaseous nitrogen (GN_2). An automatic pressure control system maintained tank pressure during firing at a value that provided the desired flow.

The JP-4 was supplied by an aircraft-type fuel pump that was pressurized from facility storage at a pressure of 60 psia. The desired engine JP-4 flow rate was provided by adjustment of a fuel bypass system back to the facility fuel storage reservoir. The seeding agent was supplied to the combustor from a seed-charged cylinder. The seeding agent was discharged from the cylinder by a piston driven with water from a 75-gal tank pressurized with gaseous nitrogen. The seed flow rate was determined by measuring the amount of water that flowed to the seed cylinder. All propellant systems incorporate provisions for purging the lines with dry nitrogen.

2.3 INSTRUMENTATION

Instrumentation was provided to measure combustor chamber pressure, propellant and seed flow rates, channel wall static pressures, channel wall temperatures, and the variation in channel length. Channel pressure and temperature sensing locations are shown in Fig. 5. Bonded strain-gage-type transducers were used to measure pressures. Propellant and seed flow rates were measured with turbine-type flowmeters. Chromel®-Alumel® (CA) thermocouples were used to measure channel wall temperature at 12 locations. Channel elongation was measured with a rectilinear potentiometer attached to the diffuser and connected to the forward transition segment with a rigid stainless steel rod (Fig. 3a).

The propellant and seed flow signals were transmitted through wave shaping converters to a magnetic tape system where they were stored for reduction at a later time by an electronic digital computer. The computer provided a tabulation of average absolute values for each 0.1-sec time increment. The pressure and temperature data were recorded on magnetic tape from a multiple-input, high-speed, analog-to-digital converter at a scan rate for each channel of 75 times/sec. A photographically recording galvanometer-type oscillograph recording at a paper speed of 10 in./sec provided an independent backup of selected instrumentation channels. Estimated measurement uncertainties, range of measurements, types of measuring and recording devices, and methods of system calibration for all measured parameters are presented in Table I (Appendix II).

SECTION III
PROCEDURE

Before each test period, the instrumentation systems were calibrated, and the propellant, seed, and coolant systems were prepared for operation. When the pressures were set to give the desired combustor flow rates, a combustor firing sequence was initiated at a time designated as T_o, which automatically controlled the sequence of events as shown typically below:

T_o	Automatic firing sequence started.
T_o + 0.60 sec	Igniter (TEB) valve opened (TEB charge depleted in approximately 0.6 sec and followed by JP-4).
T_o + 0.80 sec	LO_2 propellant valve opened.
T_o + 0.95 sec	LO_2-TEB ignition.
T_o + 1.00 sec	LO_2-TEB combustion chamber switch satisfied (75 psia); signal for main fuel valve to open.
T_o + 1.50 sec	Main fuel valve opened.
T_o + 1.70 sec	Main stage steady-state combustion chamber pressure established.
T_o + 2.00 sec	Seed valve opened.

The combustor firing was automatically terminated at a time designated as T_s which occurred when either a preselected MHD channel temperature had increased to 1200°F or when the burn time set in the automatic firing sequence had elapsed. Typical shutdown sequence of events occurred as follows:

T_s - 0.5 sec	Seed valve closed (during full-duration burn firings).
T_s	Shutdown event initiated.
T_s + 0.17 sec	LO_2 propellant valve closed (Seed valve closed during firings terminated by channel temperature limit).
T_s + 0.27 sec	Igniter valve closed.
T_s + 0.30 sec	Main fuel valve closed.

When the combustor firing was completed, the injector was purged with GN_2. After the firing, the channel was visually inspected for evidence of damage, and the electrical resistance between adjacent channel segments was measured. The resistance measurements were used to verify the absence of metallic erosion in the flow passage. (Flow of copper across the insulators located between channel segments would be reflected by low resistance measurements). When channel temperature had decreased to 100°F, preparations for the next test firing were initiated.

SECTION IV
RESULTS AND DISCUSSION

Seven firings were accomplished with an LO_2/JP-4 combustor exhausting through a 45-deg slant-wall, heat-sink, MHD generator channel to determine the aerodynamic and thermal operating characteristics of the channel under no-power conditions. A seed solution consisting of 70-percent cesium carbonate and 30-percent water (by weight) was injected into the combustion chamber during firing to provide a high ion concentration. Firings were performed with variations in seed flow rate, combustor chamber pressure, and propellant mixture ratio; all firings were accomplished with the channel exhausting to atmospheric pressure.

Specific test objectives were to determine the channel axial pressure distribution and the variation in channel temperature with time and to confirm that channel construction was adequate to contain the combustor exhaust gases. Channel operating characteristics, static pressure distribution, and temperature measurements are discussed in the sections which follow. Average combustor operating conditions during the seven firings are presented in Table II.

4.1 CHANNEL OPERATING CHARACTERISTICS

Seven firings, having burn times ranging from 4.6 to 7.6 sec, were accomplished through the channel with no channel maintenance required between firings. Total burn duration was 41.5 sec. No luminous gas leakage between channel segments was observed during any firing.

The analog variations in upstream channel pressure, combustor chamber pressure, and propellant flow rates during a typical combustor

ignition are presented in Fig. 6. No extreme excursions in measured channel pressure were observed during the ignition phase of any of the seven firings.

The variation in the length of the segmented portion of the channel due to thermal expansion during a typical firing is shown in Fig. 7. The maximum channel length increase was 0.174 in. and occurred approximately 1 sec after combustor shutdown. For the firing shown in Fig. 7, the time required for the channel to contract to within 0.050 in. of the original length was 11 hr. The combustor propellant system postfire gaseous nitrogen purge systems were inactive during this cool-down period. The time required for the channel to contract to within 0.05 in. of the original length with purge systems activated was approximately 45 min.

4.2 CHANNEL STATIC PRESSURE DISTRIBUTION

The channel was instrumented for measurement of static pressure at 11 axial positions (Fig. 5). The measured channel axial pressure distribution is presented in Fig. 8 for the seven firings. Variations in chamber pressure, propellant mixture ratio, and seed flow had no apparent effect on the ratio of channel-to-chamber pressure. The average pressure ratio decreased from 0.34 near the channel inlet to 0.035 in the constant area diffuser and exhibited a trend similar to that predicted from simplified theoretical considerations.

Measurements of the channel-to-chamber pressure ratio during individual firings were within 10 percent of the average for the seven firings. This is a contrast to the large pressure fluctuations observed during firings accomplished through a 10-in.-long, copper test fixture (Ref. 2) which incorporated a 2.0-in.-diam, 3.6-in.-long cylindrical inlet followed by a 6.4-in.-long section which diverged at a conical half-angle of 2.5 deg. It was reported in Ref. 2 that the pressure in the cylindrical inlet of the test fixture fluctuated from 0.33 to 0.63 percent of chamber pressure in an apparently random fashion at combustor operating conditions comparable to those existing for the firings reported herein. The 1-deg divergence in the inlet of the 45-deg-slant, segmented-wall, MHD channel was effective in stabilizing the flow as evidenced by the narrow range of channel inlet-to-combustor chamber pressure ratios (0.32 to 0.36) measured during the seven firings.

4.3 CHANNEL TEMPERATURE VARIATION

The MHD channel contained 12 CA thermocouples installed in 0.063-in.-diam ports drilled on the minor axis of the elliptically shaped channel segments at the axial locations shown in Fig. 5. The thermocouple ports were drilled to within 0.125 in. of the internal flow passage. Commercially procured CA thermocouple probes housed in a metallic sheath (Fig. 9) were inserted in the ports. The probes were positioned in the ports so that the thermocouple junction was in intimate contact with the channel.

The variation in measured temperature from a representative thermocouple probe during several firings is shown in Fig. 10. The gasdynamic operating conditions were stable during all firings. It is believed that mechanical contact between the probe tip and channel was not maintained at all times, as evidenced by the abrupt change in rate at which measured channel temperature increased during several firings (Fig. 10). To support this thesis, an additional thermocouple was installed on the surface of the diffuser at the same axial location as a thermocouple probe. The variation in diffuser temperature, measured with both the diffuser surface thermocouple and the probe thermocouple, is presented in Fig. 11. The surface thermocouple was more responsive to temperature changes than the probe thermocouple which was designed to measure the temperature near the flow passage. It is therefore concluded that all transient temperature measurements obtained with the thermocouple probes are subject to question because the thermocouple junctions located on the probe tip did not at all times maintain contact with the channel.

The combustor gaseous nitrogen purge systems were utilized after all firings (except firing 77.1) to decrease the time required for channel cooldown. The average channel heating rate during firing 77.1 was calculated by assuming that all thermal energy transferred to the channel during the firing remained in the channel after the firing until the measured channel temperature stabilized (which is indicative that the segment temperature was uniform). This assumption is considered valid because the primary mechanism for heat transfer from the channel after a firing with no purges is by free convection; the total free-convection heat loss during the approximate 15-sec period required for the channel temperature to stabilize is considered negligible. The method used to determine average channel heating rates is shown in Fig. 12 and requires only that the channel thermocouple probes sense a steady-state temperature.

The variation in the average channel heat rate during firing 77.1 is presented in Fig. 13 as a function of axial position. The heat rate

decreased from 4.50 Btu/sec-in.^{2} at 10.7 in. from the channel inlet to 1.26 Btu/sec-in.^{2} at 35.7 in. from the channel inlet. These data are in excellent agreement with the theoretical heat-transfer rates presented in Ref. 3 where the heat-transfer rate at the combustor nozzle exit (or channel inlet) was calculated to be 4.8 Btu/sec-in.^{2}.

SECTION V
SUMMARY OF RESULTS

Seven combustor firings were accomplished to determine the aerodynamic and thermal operating characteristics of a 45-deg slant-wall, heat-sink, MHD generator channel under no-power conditions. The test results are summarized as follows:

1. Total burn duration accumulated during the seven combustor firings was 41.5 sec. No luminous gas leakage from between channel segments was observed during any firing.
2. The ratio of measured channel-to-chamber pressure was not dependent on chamber pressure, propellant mixture ratio, or seed flow rate. The ratio decreased from 0.34 at the channel inlet to 0.03 at the channel exit.
3. The channel temperature instrumentation was not suitable for determining the channel transient temperature variation.
4. The average channel heat rate decreased from 4.5 Btu/sec-in.^{2} at the inlet to 1.3 Btu/sec-in.^{2} at the exit.

REFERENCES

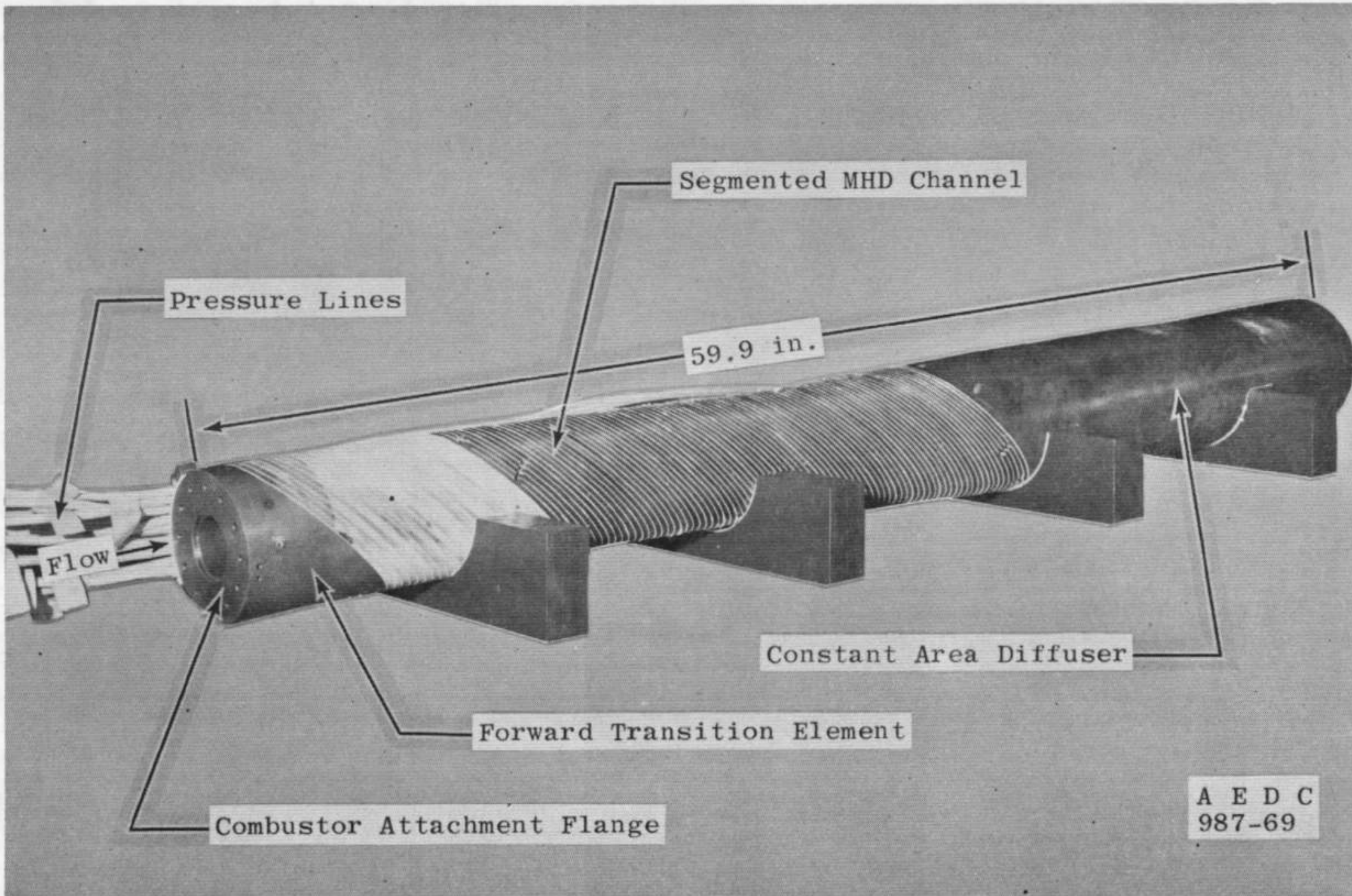
1. Pape, Thomas A. "One Megawatt Diagonal Conducting Wall MHD Generator." AFAPL-TR-69-3, May 12, 1969.
2. "Airborne MHD Generator Development Program." Technical Report HMD-R23-69, Chrysler Corporation, Space Division, Huntsville Operation, June 30, 1969.

3. Darlington, C. R., Gilburth, R. E., and Ballard, R. S. "Design Characteristics and Performance of a Combustor for Use as an Ionized Gas Source in Magnetohydrodynamic Power Generation Studies." AEDC-TR-69-167 (AD858379), September 1969.

4. Nelius, M. A., LeBoeuf, R. J., and McNeese, J. D. "Aerodynamic and Thermal Operating Characteristics of a 45-deg-Slant, Segmented Wall, Magnetohydrodynamic Generator Channel under No-Power Conditions." AEDC-TR-68-221 (AD841817), October 1968.

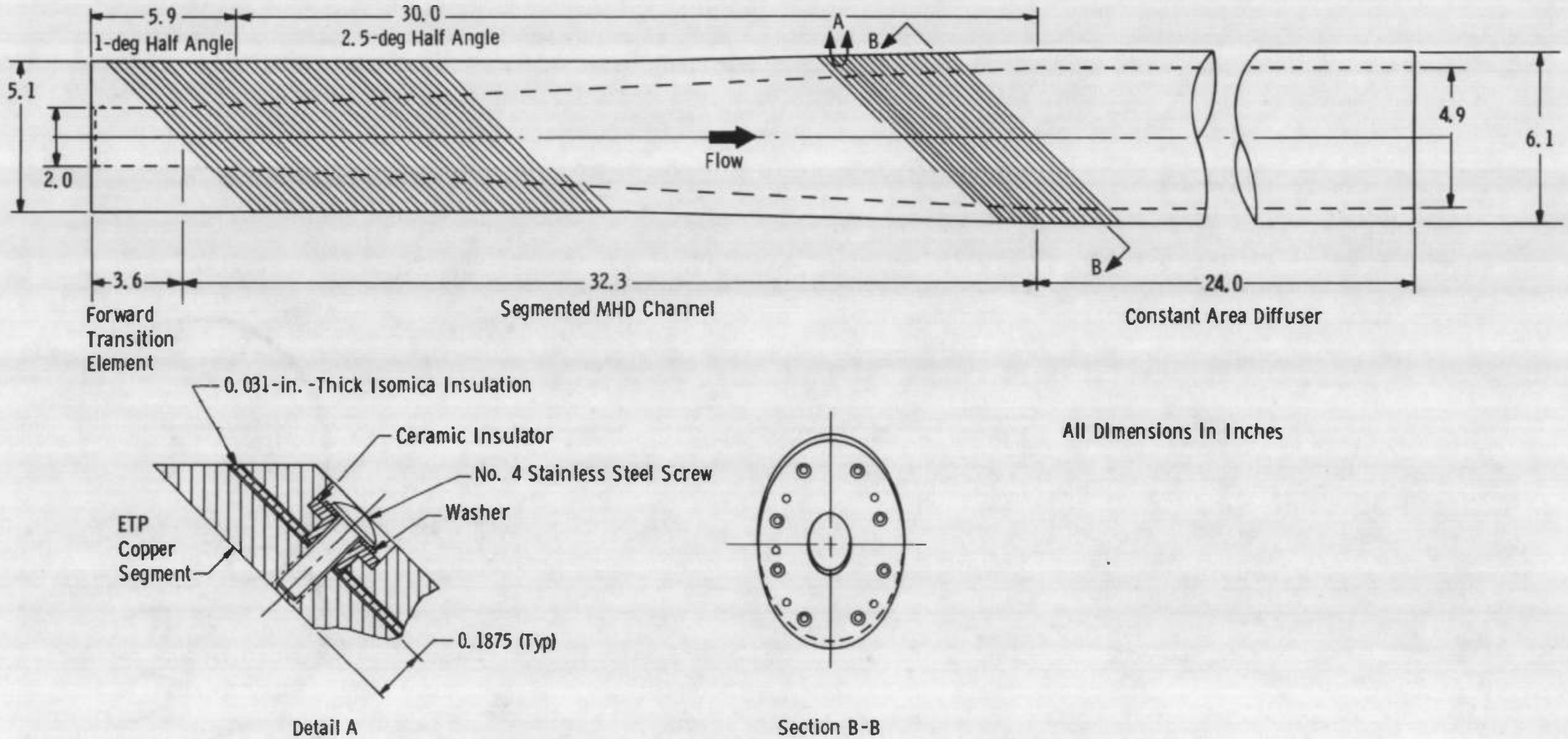
APPENDIXES

I. ILLUSTRATIONS
II. TABLES



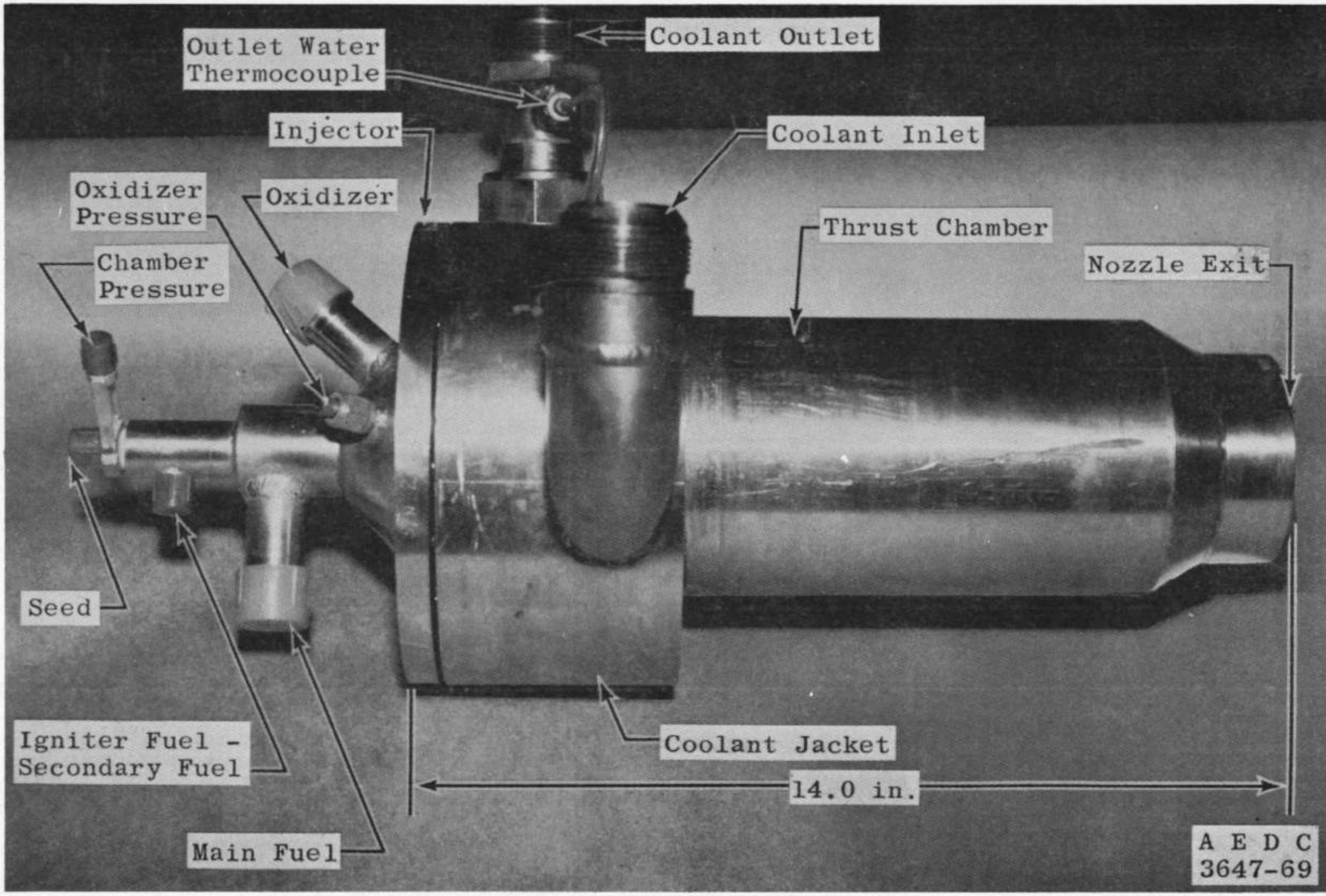
a. Photograph

Fig. 1 MHD Generator Channel Assembly



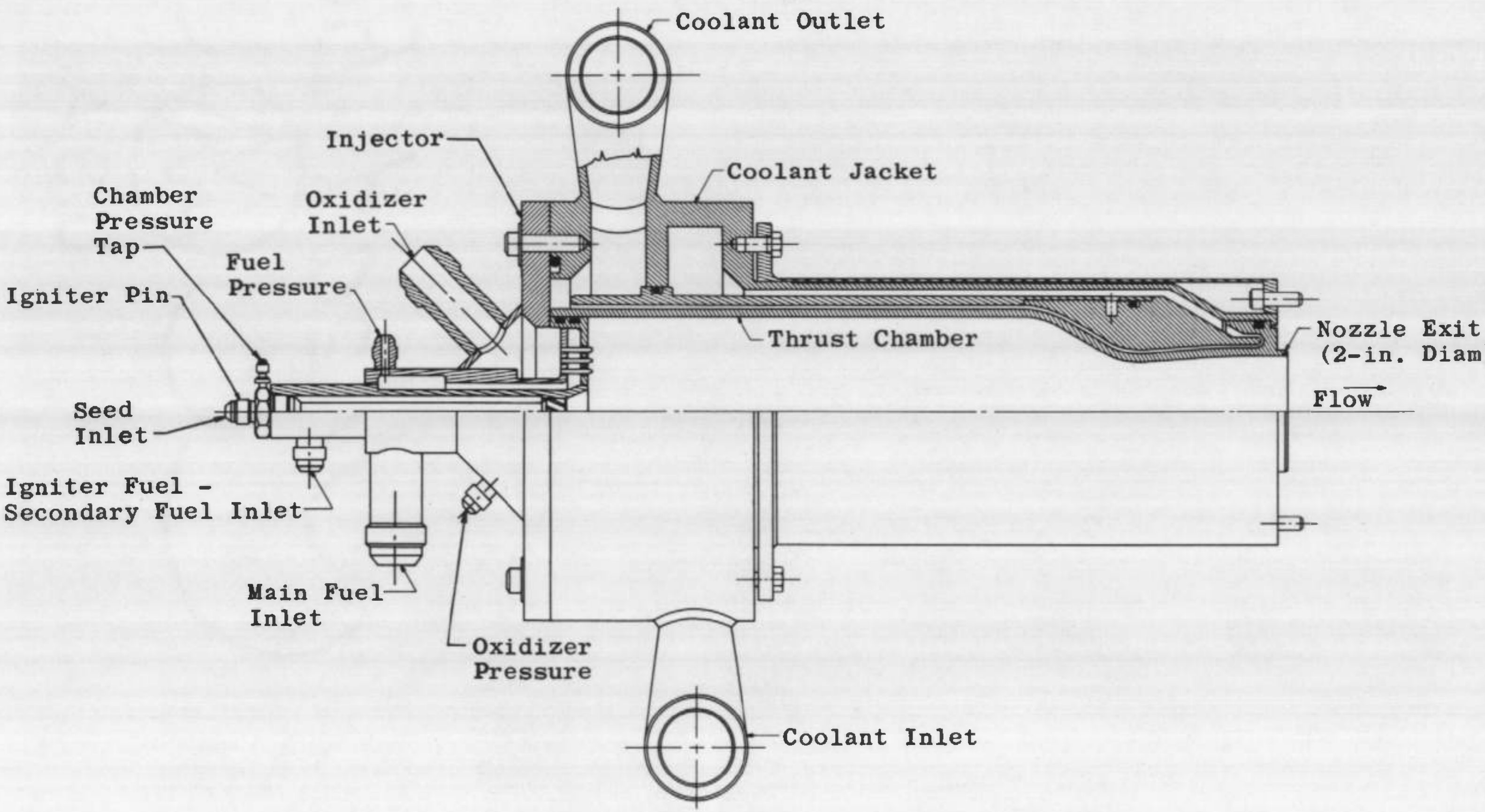
b. Schematic

Fig. 1 Concluded



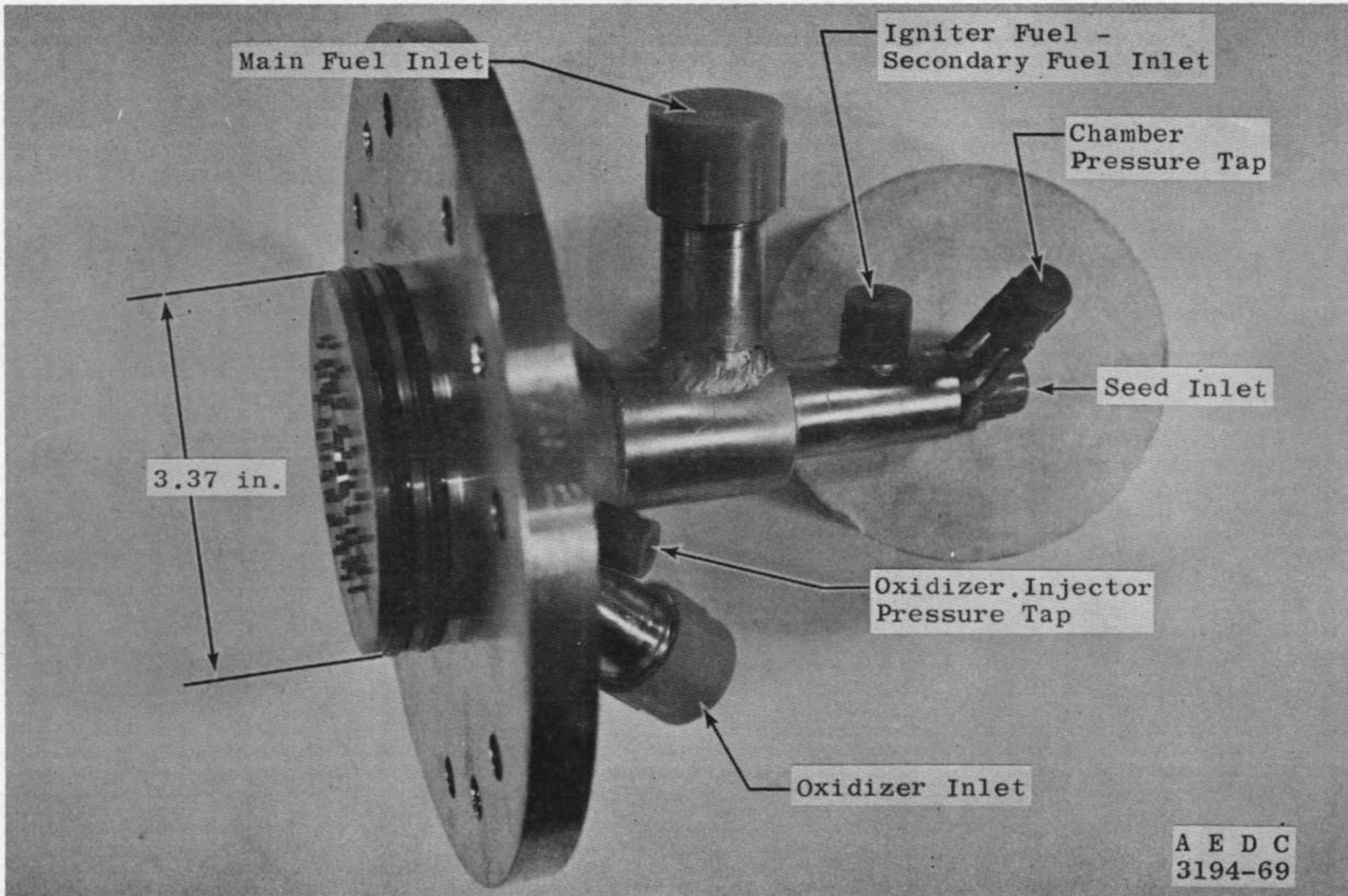
a. Assembly Photograph

Fig. 2 MHD Combustor

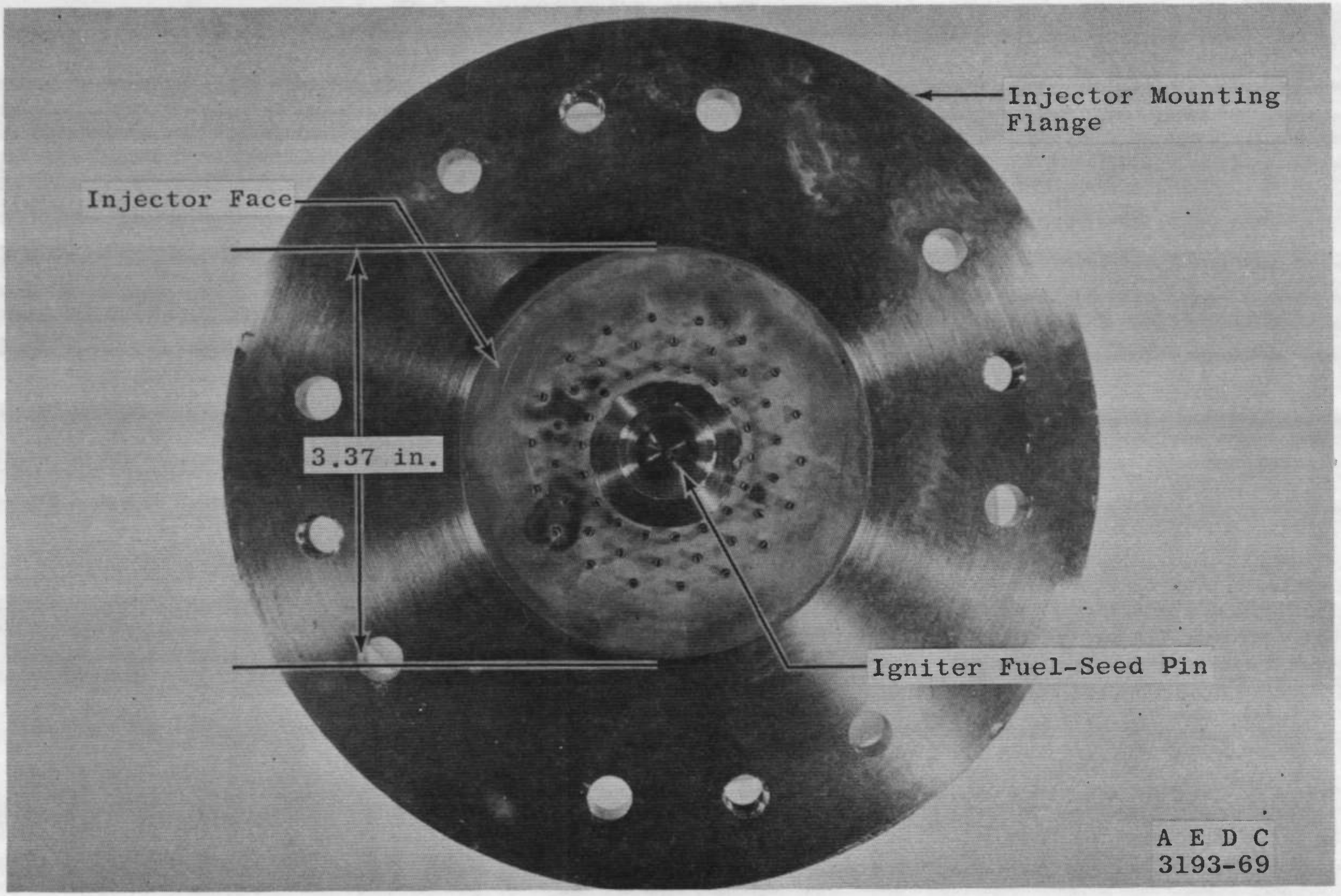


b. Assembly Schematic

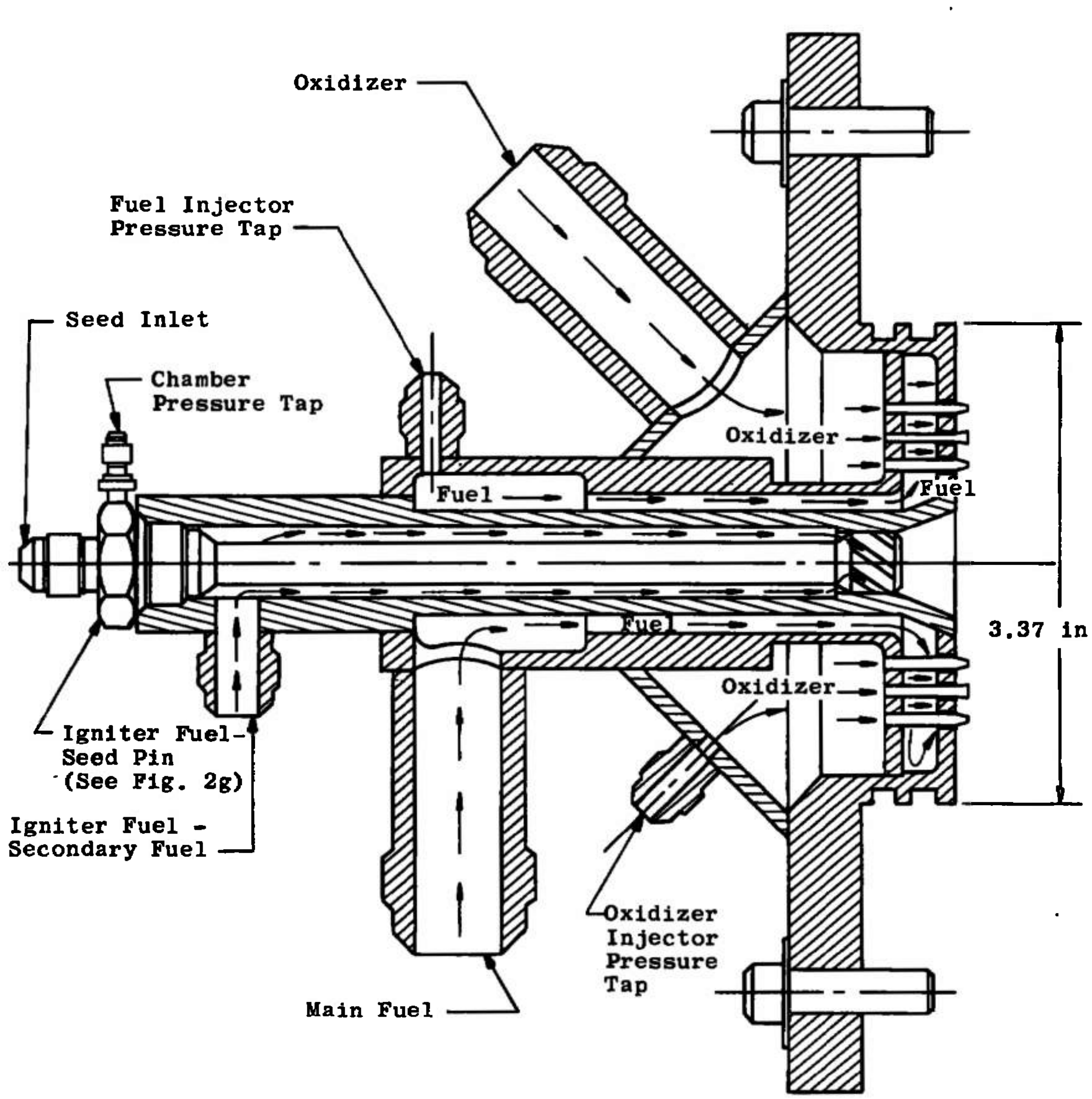
Fig. 2 Continued



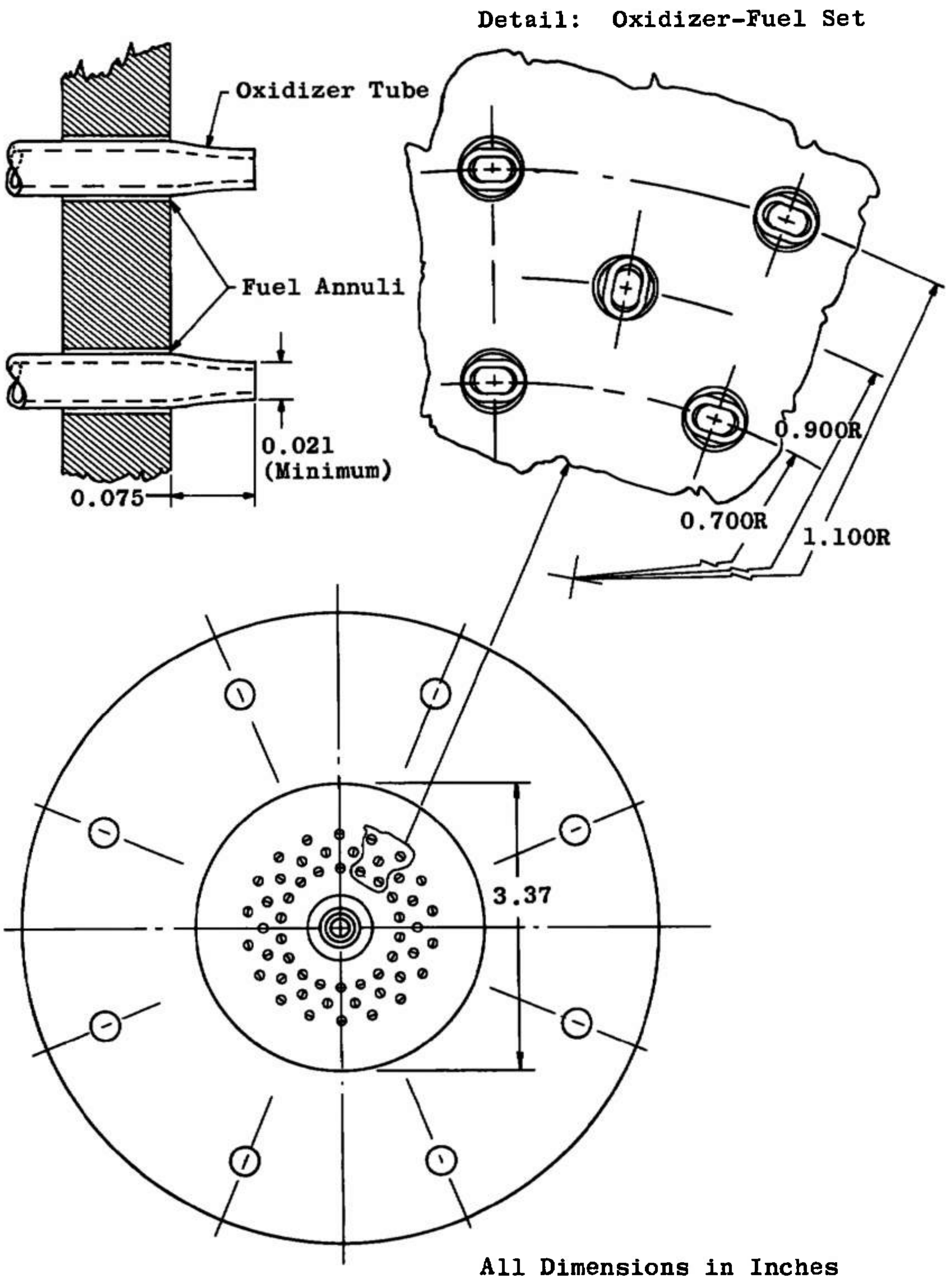
c. Injector Photograph
Fig. 2 Continued



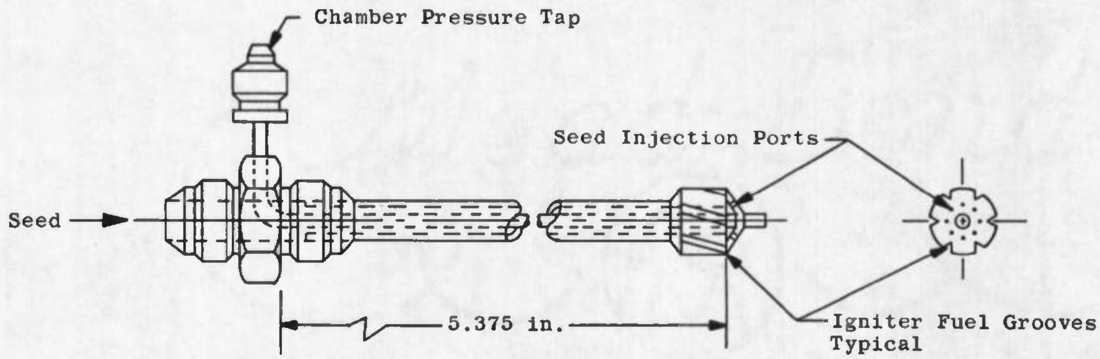
d. Injector Face Photograph
Fig. 2 Continued

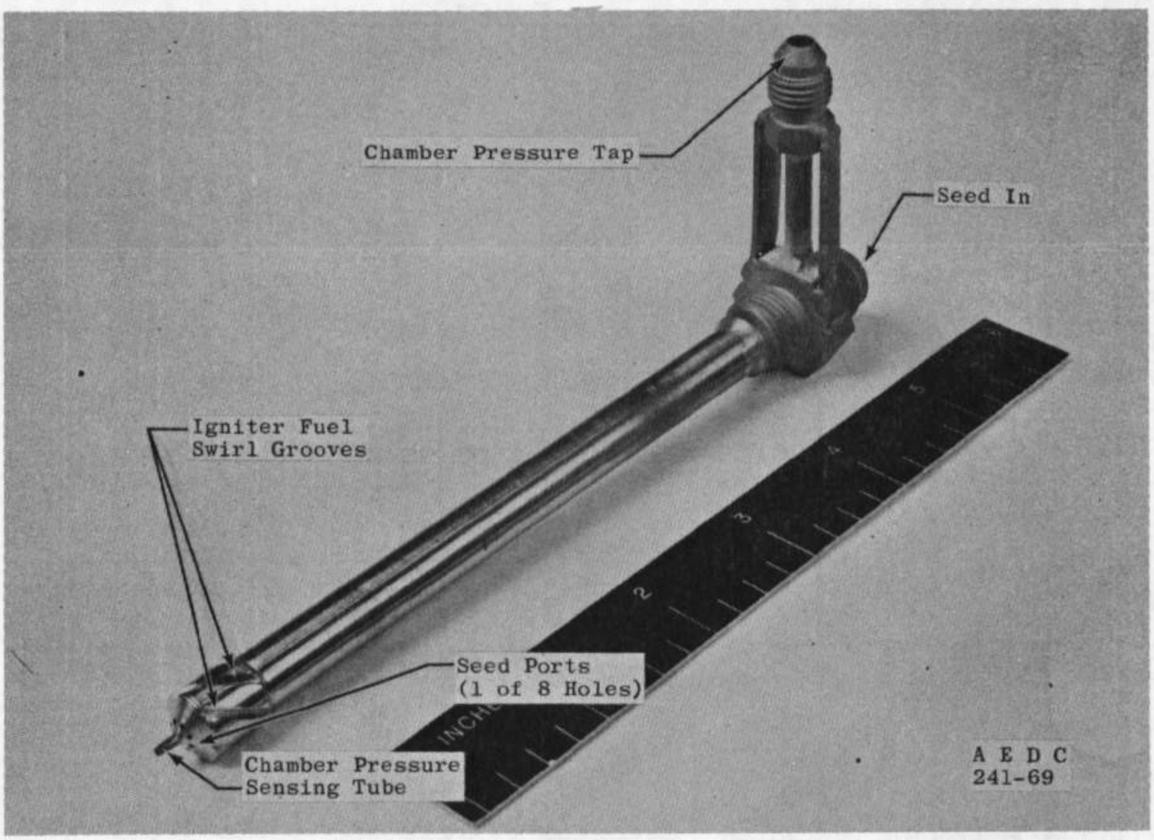


e. Injector Schematic
Fig. 2 Continued

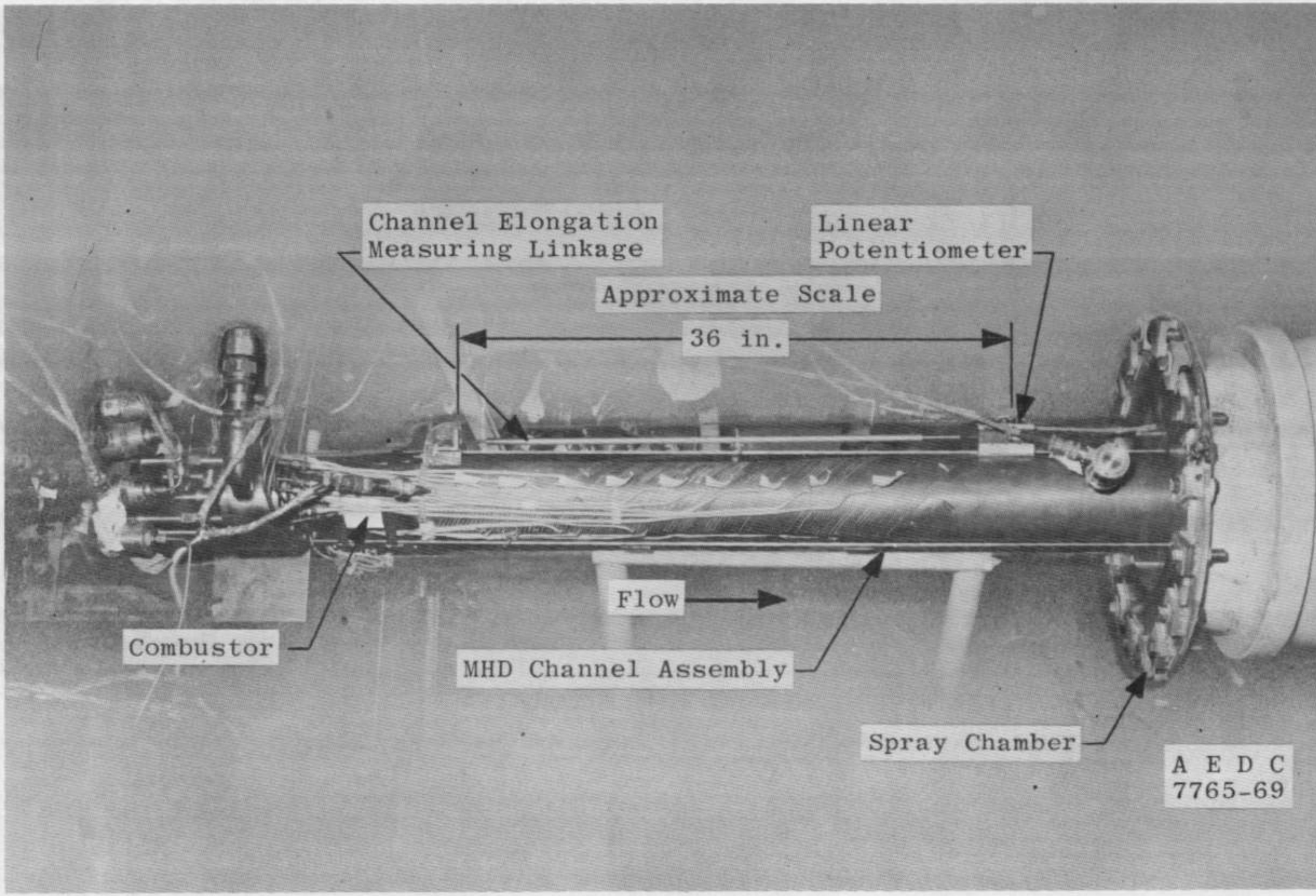


f. Injector Face Schematic
Fig. 2 Continued



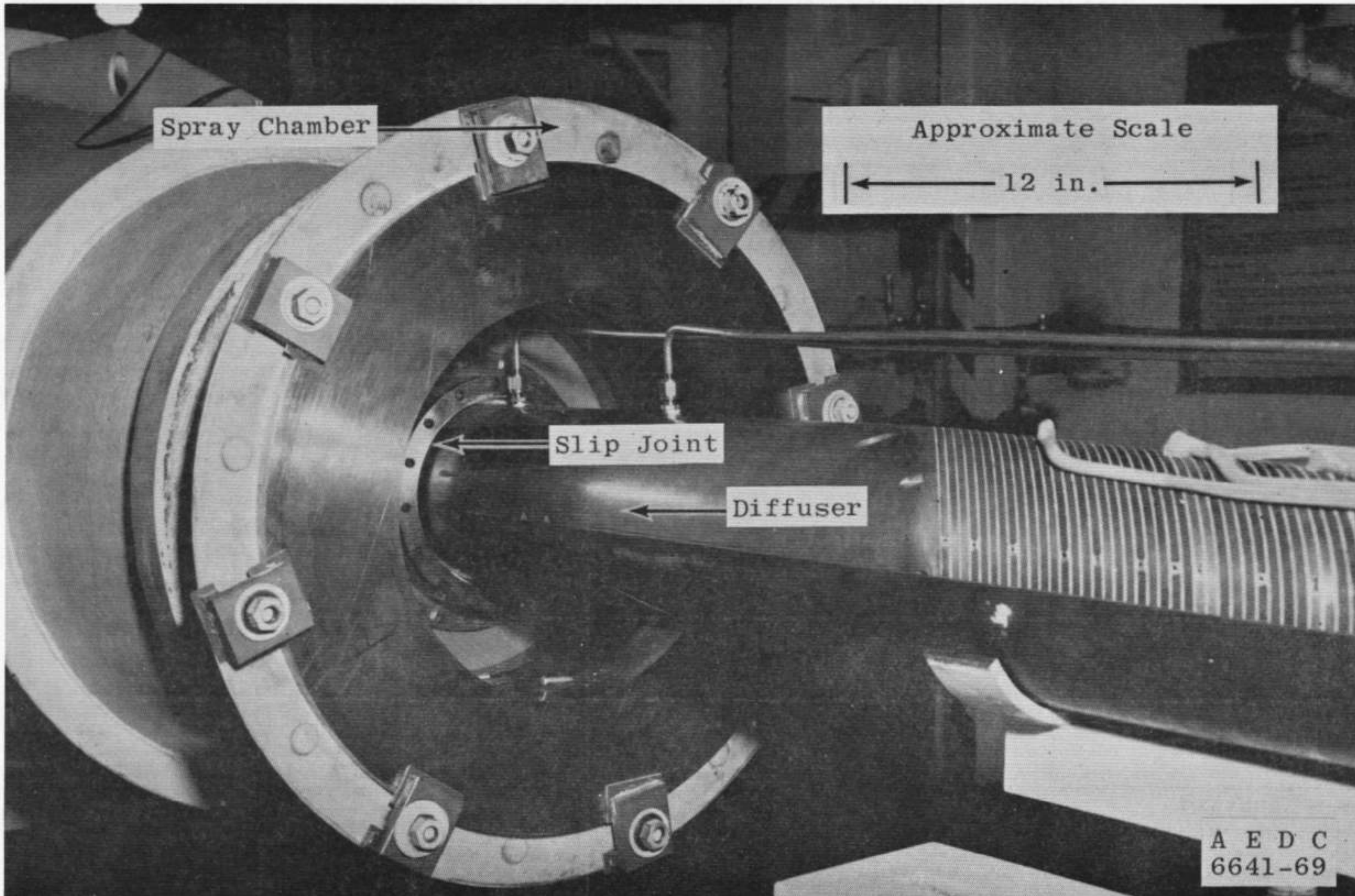


g. Igniter Fuel-Seed Pin
Concluded



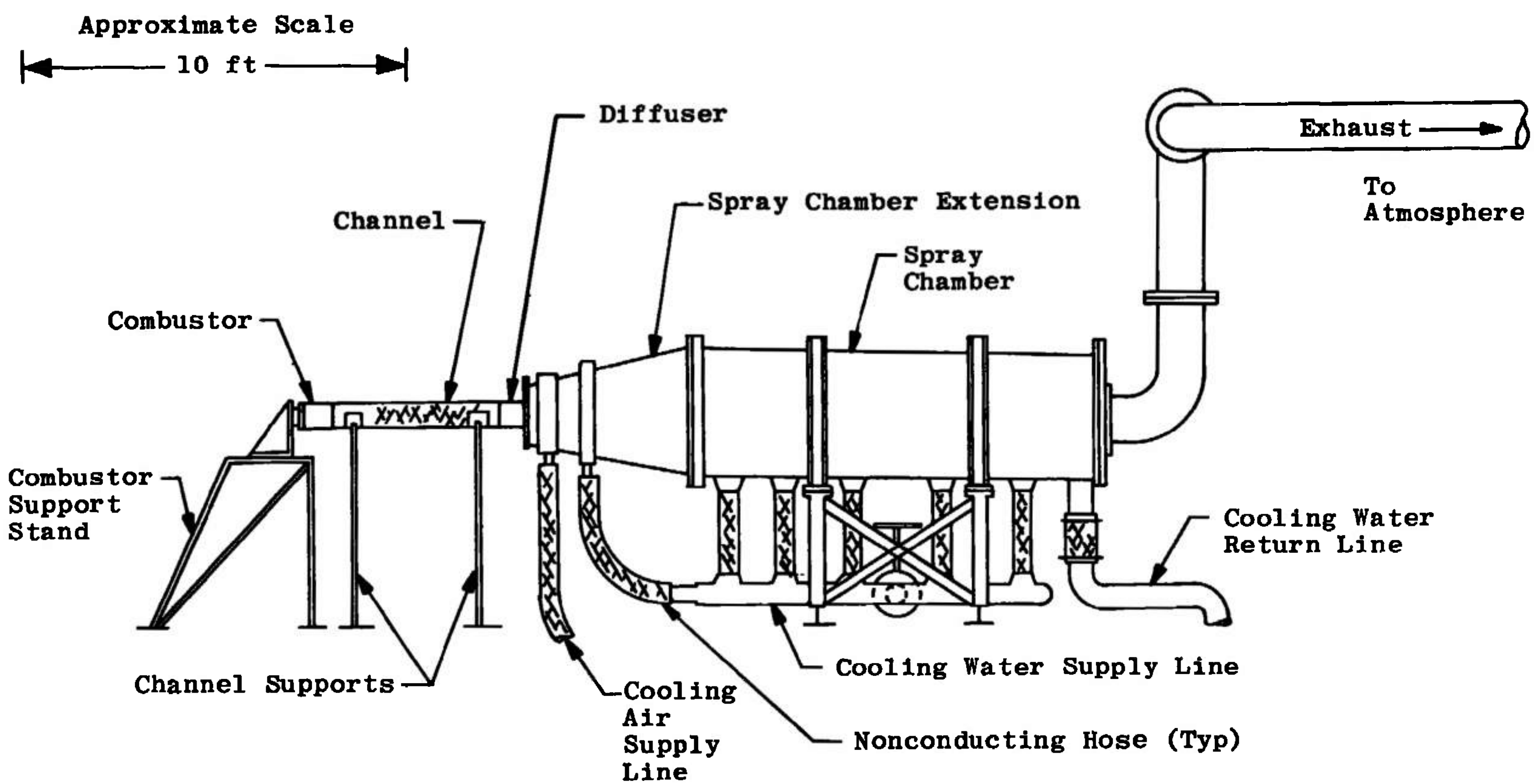
a. Photograph

Fig. 3 Installation of MHD Generator Assembly in Propulsion Research Area (R-2C-4)



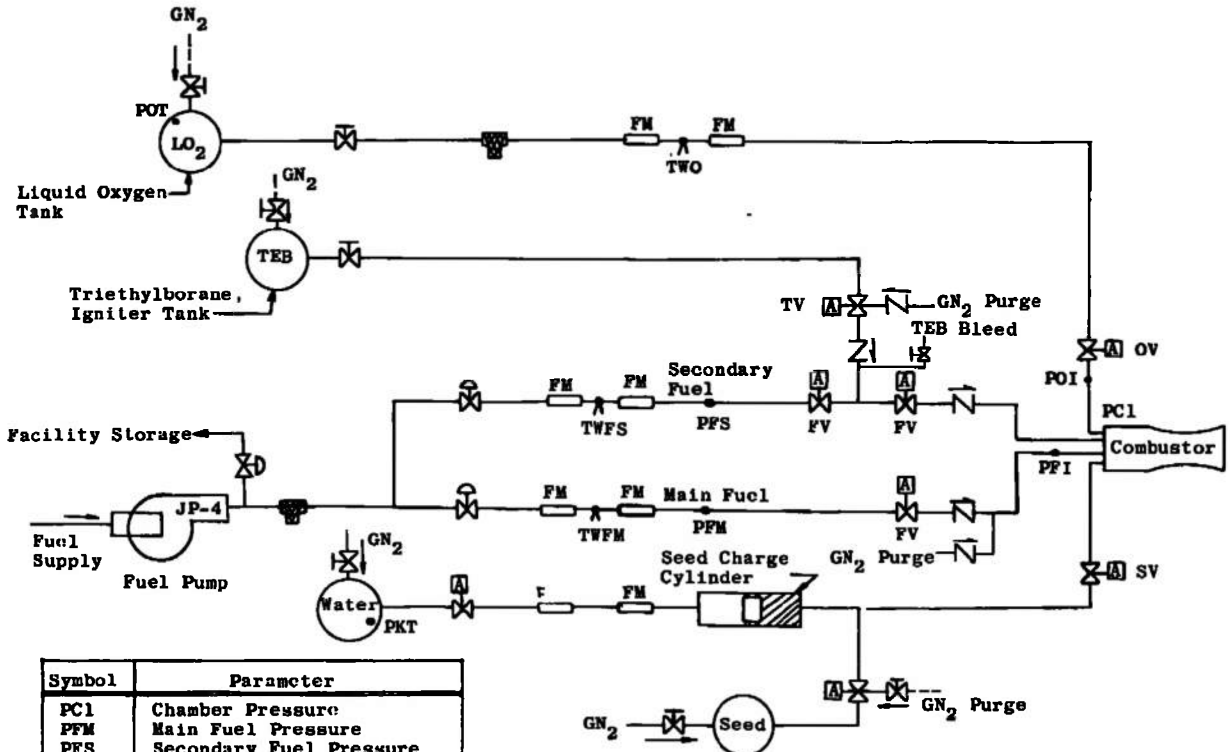
b. Diffuser-Spray Chamber Photograph

Fig. 3 Continued



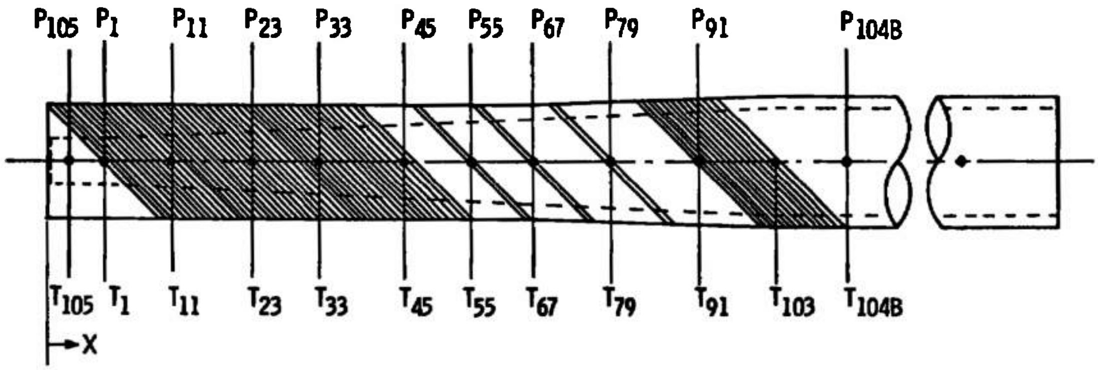
c. Schematic

Fig. 3 Concluded



Symbol	Parameter
PC1	Chamber Pressure
PFM	Main Fuel Pressure
PFS	Secondary Fuel Pressure
POT	LO_2 Tank Pressure
PKT	Seed Tank Pressure
POI	LO_2 Injector Pressure
PFI	Fuel Injector Pressure
TWFM	Main Fuel Temperature
TWFS	Secondary Fuel Temperature
TWO	LO_2 Temperature
FV	Fuel Valve
OV	LO_2 Valve
TV	TEB Valve
SV	Seed Valve
FM	Flowmeter
GN_2	Gaseous Nitrogen

Fig. 4 Propellant and Seed Flow Schematic



Element No.	Distance from Channel Inlet, X, in.	Parameter Measured: P - Pressure T - Temperature
105	1.1	P_{105} , T_{105}
1	3.7	P_{1} , T_{1}
11	6.7	P_{11} , T_{11}
23	10.2	P_{23} , T_{23}
33	13.2	P_{33} , T_{33}
45	16.7	P_{45} , T_{45}
55	19.6	P_{55} , T_{55}
67	23.2	P_{67} , T_{67}
79	26.7	P_{79} , T_{79}
91	30.2	P_{91} , T_{91}
103	33.7	- , T_{103}
104B	39.2	P_{104B}, T_{104B}

Fig. 5 Location of Channel Pressure and Temperature Measuring Ports

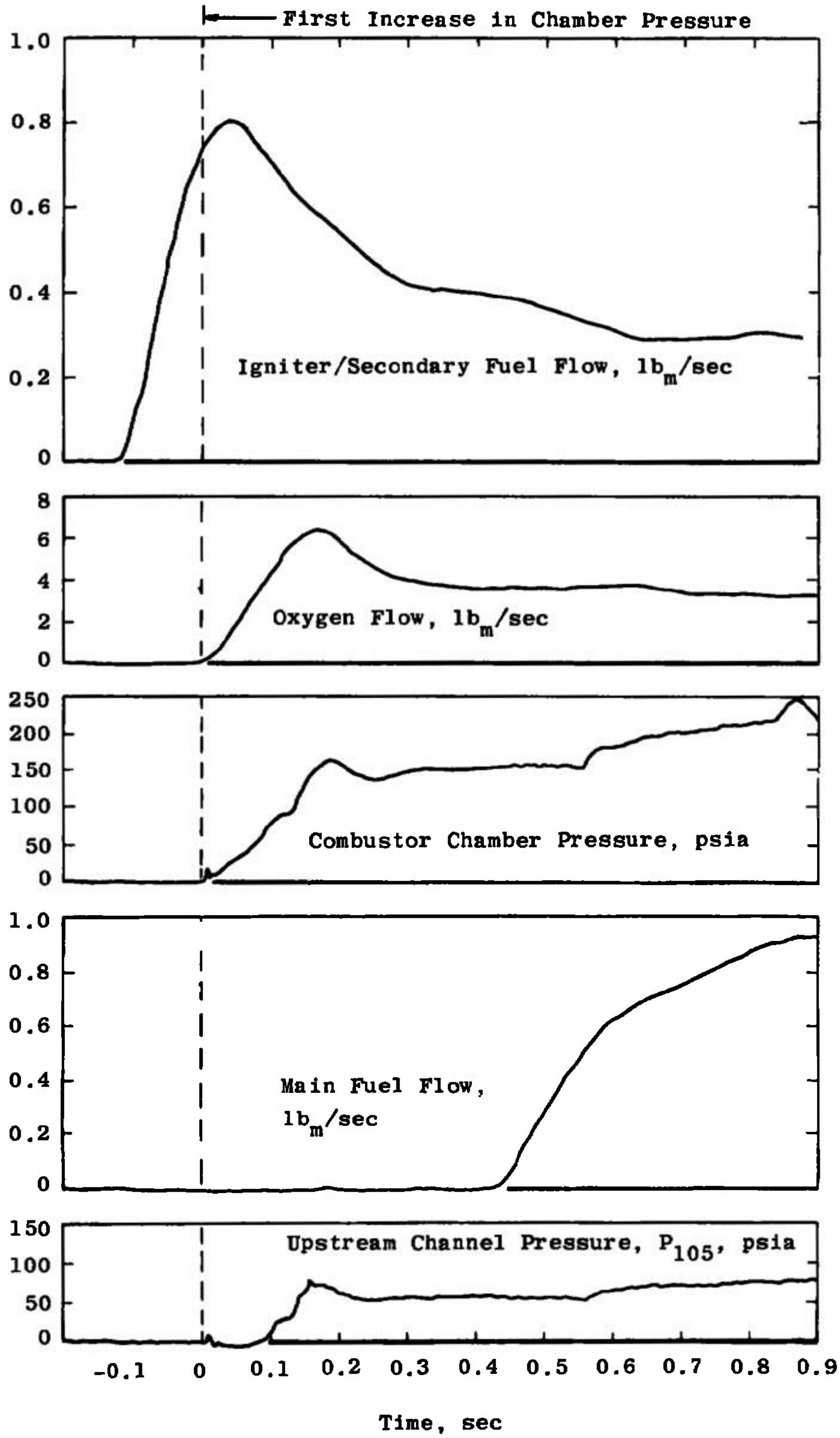


Fig. 6 Typical Combustor Ignition Transient

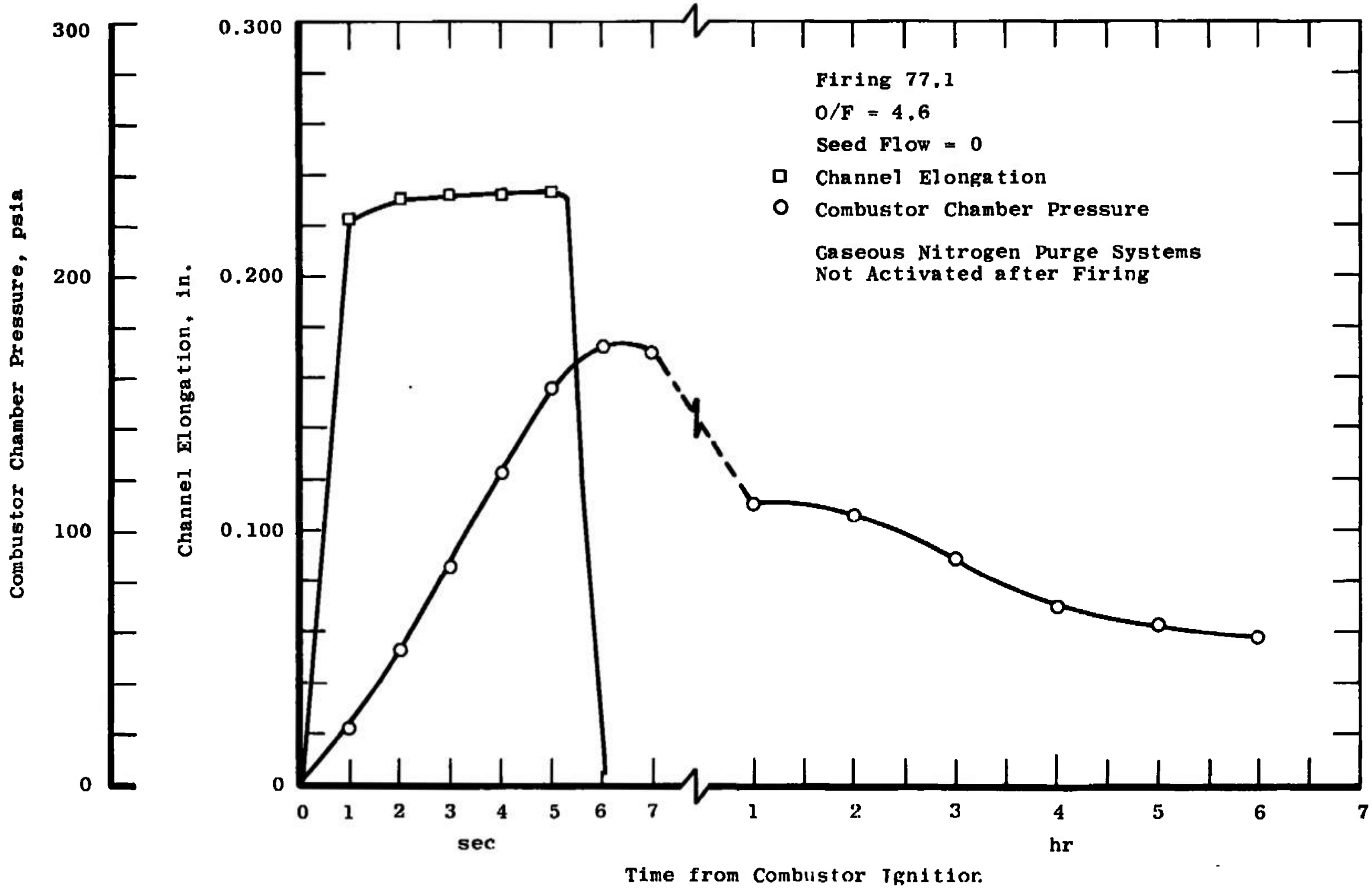


Fig. 7 Variation in Channel Length during and after a Firing

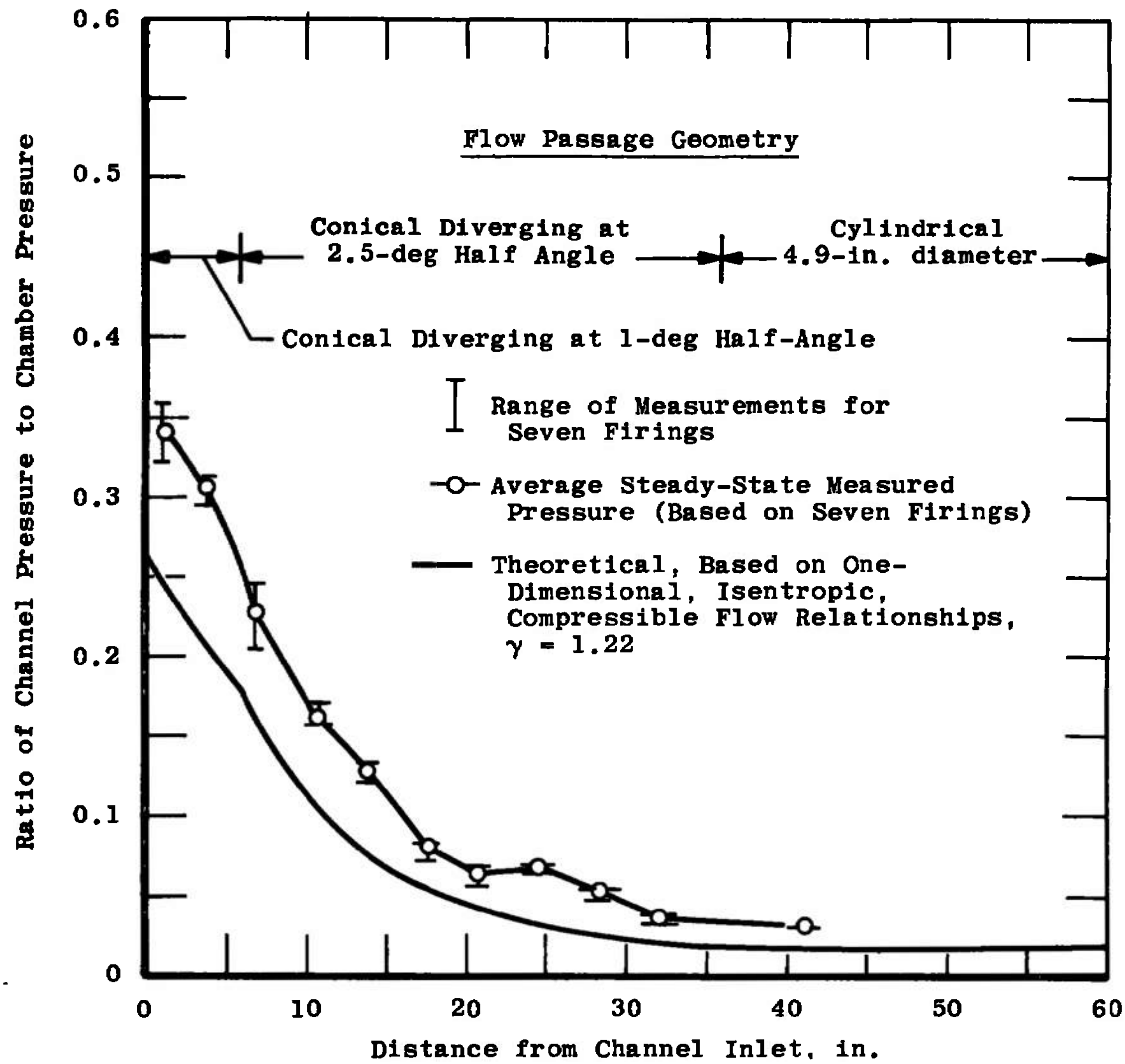


Fig. 8 Channel Axial Pressure Profile during Combustor Firing

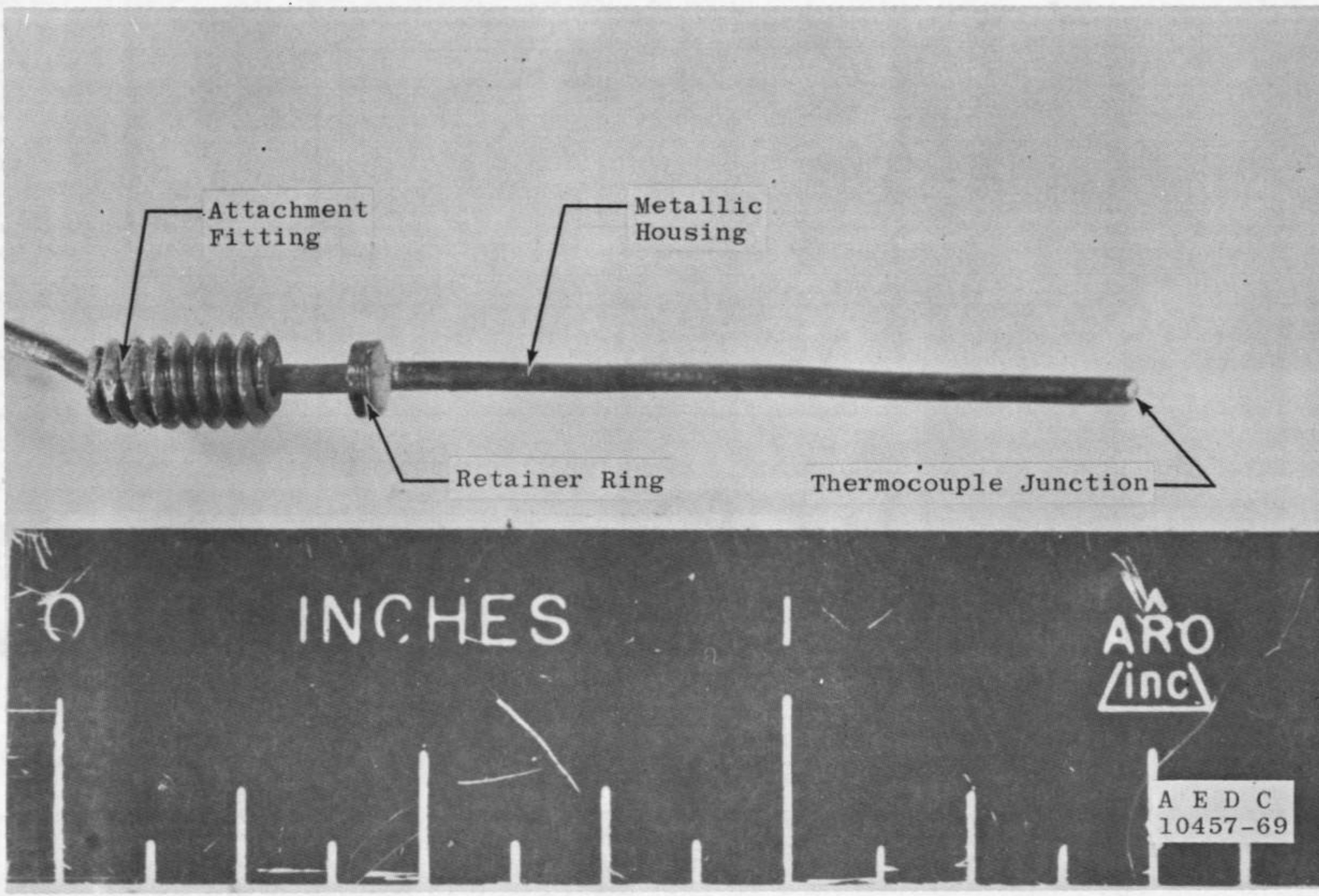


Fig. 9 Photograph of Typical Channel Thermocouple Probe

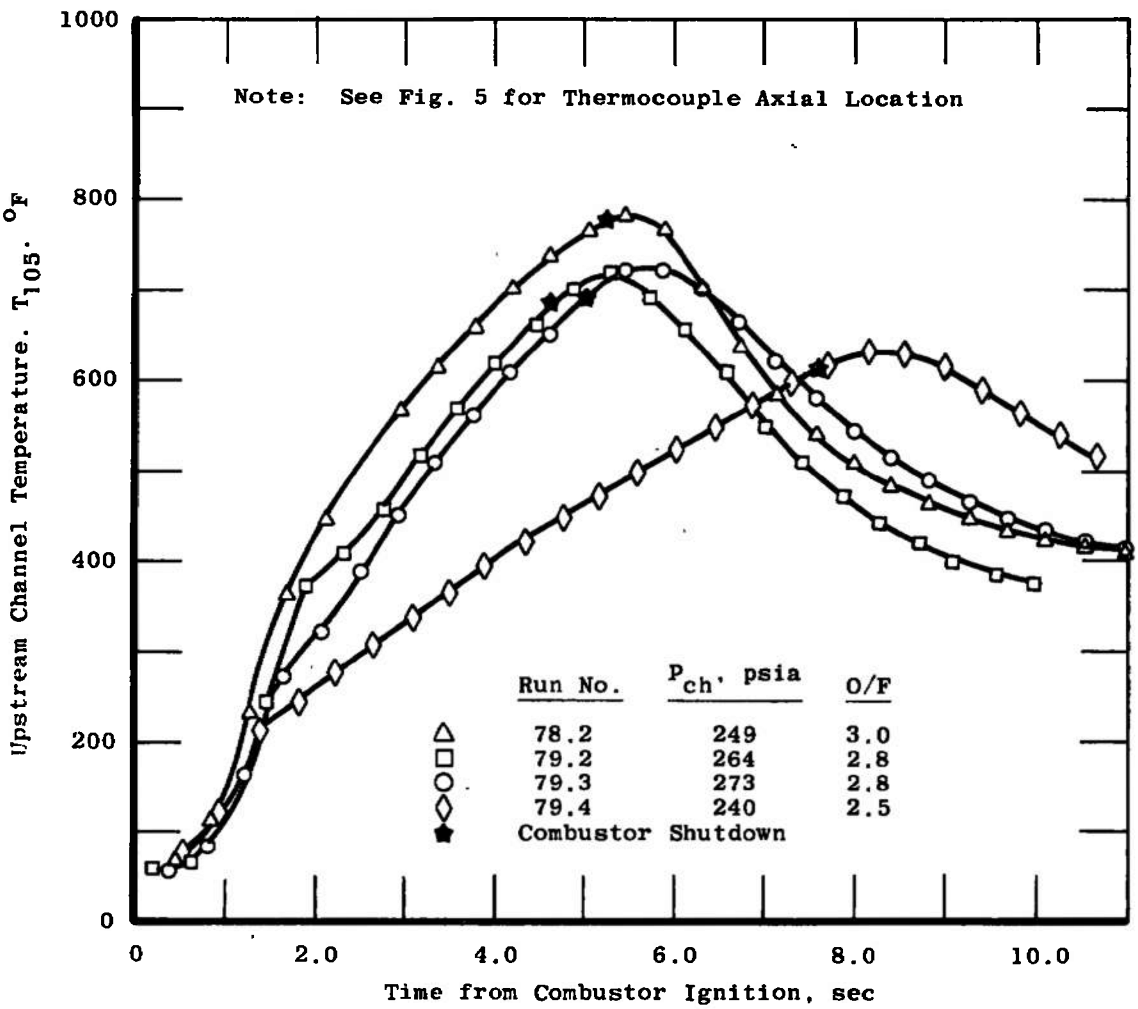


Fig. 10 Variation in Measured Upstream Channel Temperature during Several Firings

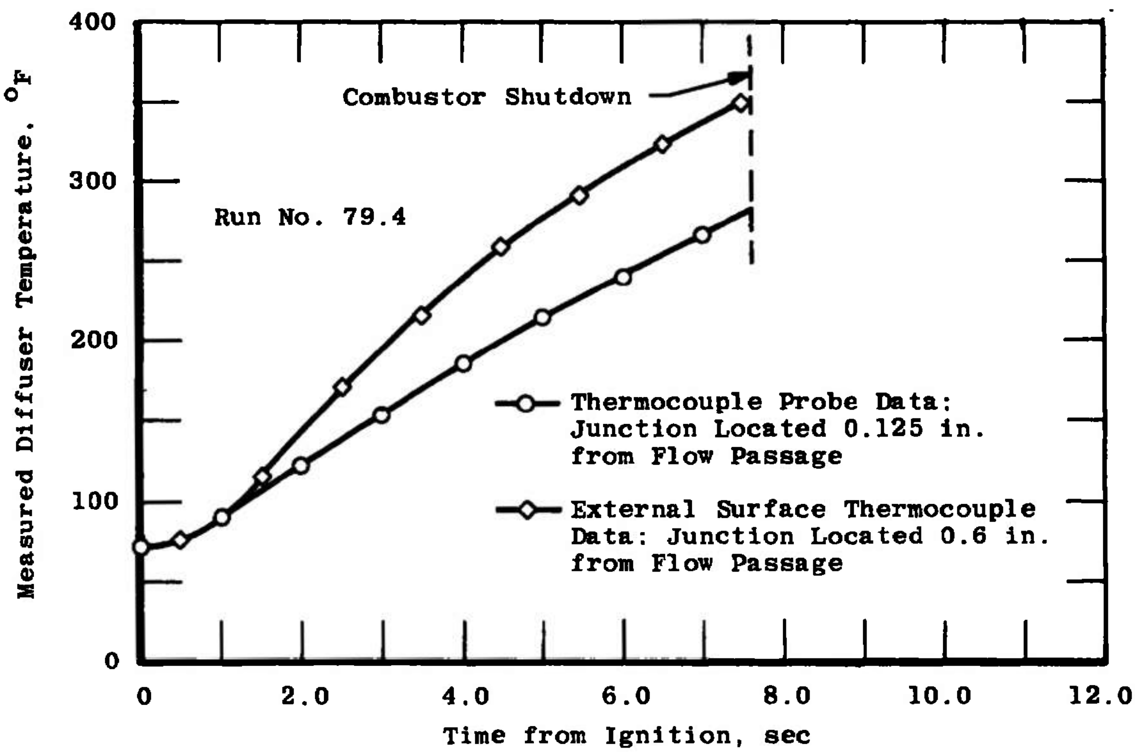
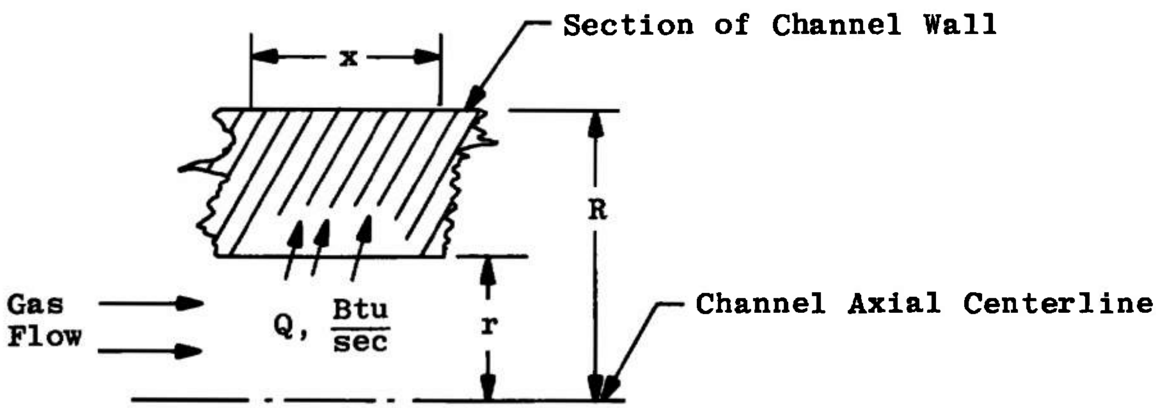


Fig. 11 Comparison of Measured Diffuser Temperature Variation from Thermocouples Located at Varying Distances from Flow Passage



$$\frac{Q}{A} = \frac{mc_p \Delta T}{(2\pi r x) t_b}$$

where

$\frac{Q}{A}$ = Heat rate per unit area, $\frac{\text{Btu}}{\text{sec-in.}^2}$

$\frac{m}{2\pi r x}$ = Mass of copper heat sink per unit area, $\frac{\text{lb}_m}{\text{in.}^2}$

= $\rho[\pi x(R^2 - r^2)]$ where ρ is the density of copper, 0.323 $\text{lb}_m/\text{in.}^3$

ΔT = Postfire, equilibrium channel temperature - Prefire channel temperature, $^\circ$F

t_b = Combustor burn duration, sec

c_p = Specific heat of copper, 0.0915 $\frac{\text{Btu}}{\text{lb}_m\text{-}^\circ\text{F}}$

$$\frac{Q}{A} = \frac{\rho c_p \Delta T}{2 r t_b}(R^2 - r^2)$$

Fig. 12 Method of Determining Average Channel Heat Rate

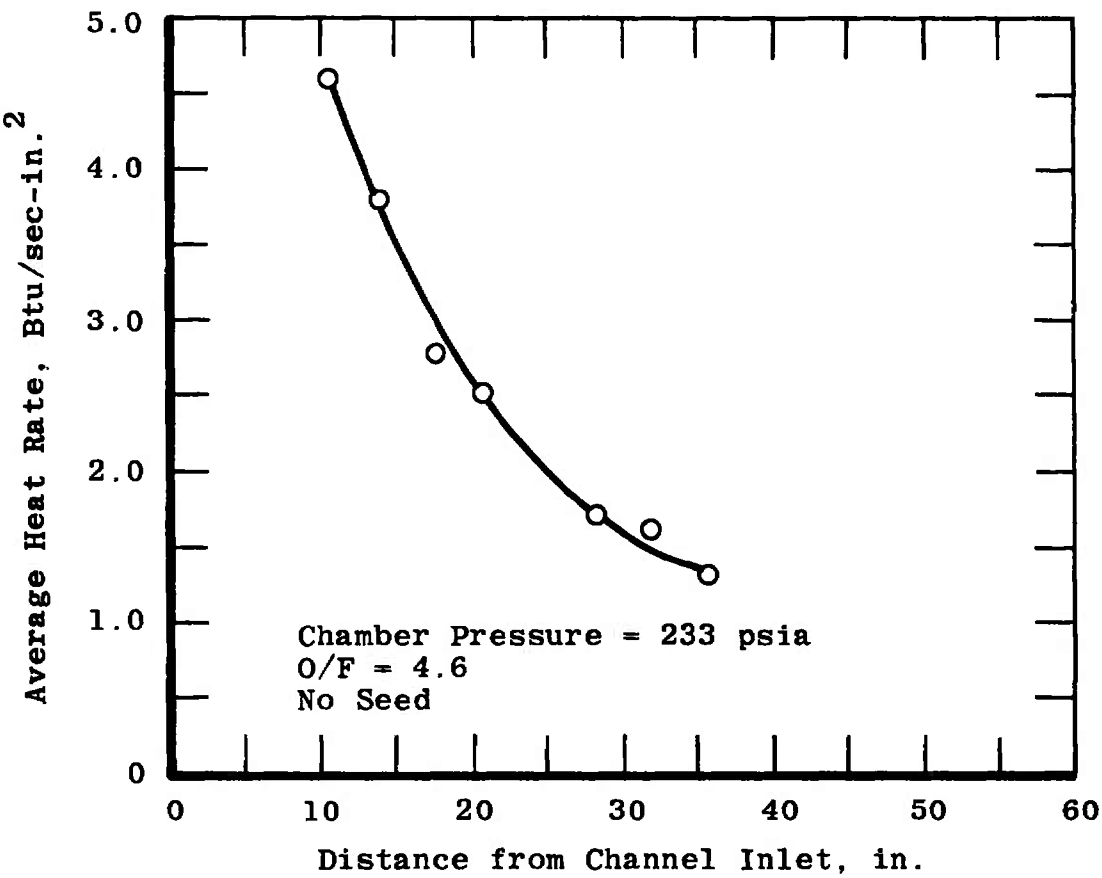


Fig. 13 Variation in Average Heat Rate with Distance from Channel Inlet

TABLE I
ESTIMATE OF MEASUREMENT SYSTEM UNCERTAINTY

Parameter Designation	Estimated Measurement Uncertainty - 2 Sigma: Steady-State: Percentage of Reading	Estimated Measurement Uncertainty - 2 Sigma: Steady-State: Units of Measurement	Range of Measurement	Type of Measuring Device	Type of Recording Device	Method of System Calibration
Combustor Chamber Pressure	±0.5	---	220 to 270 psia	Bonded Strain-Gage-Type Pressure Transducers	Sequential Sampling, Millivolt-to-Digital Converter and Magnetic Tape Storage Data Acquisition System	Resistance Shunt Based on the Standards Laboratory Determination of Transducer Applied Pressure versus Resistance Shunt Equivalent Pressure Relationship
Secondary Fuel Flow Rate	±1.53	---	0.25 to 0.50 lb/sec	Turbine Volumetric Flow Transducers		Frequency Substitution Based on the Standards Laboratory Determination of Transducer Water Volumetric Flow versus Frequency Output Relationship
Main Fuel Flow Rate	±2.79	---	0.8 to 1.4 lb/sec			
LO_2 Flow Rate	±2.35	---	2.0 to 3.0 lb/sec			
Seed Flow Rate	±1.76	---	0.1 to 0.6 lb/sec			
MHD Channel Pressure	±0.125 psi		10 to 25 psia	Bonded Strain-Gage-Type Pressure Transducers		Resistance Shunt Based on the Standards Laboratory Determination of Transducer Applied Pressure versus Resistance Shunt Equivalent Pressure Relationship
	±0.5	---	25 to 100 psia			
MHD Channel Temperature	---	±3°F	50 to 530 psia	Chromel-Alumel Tempera- Temperature Transducers		Millivolt Substitution Based on the NBS Temperature versus Millivolt Tables
	±(1.70°F + 0.25 percent of Reading)		530 to 1200°F			
MHD Channel Axial Growth	---	±0.011 in.	0.0 to 0.175 in.	Rectilinear Potentiometer	Null-Balance Potentiometer Strip-Chart Recorder	In-Place Measurement of Physical Dimensions versus Transducer Output

TABLE II
SUMMARY OF COMBUSTOR OPERATION CONDITIONS

Run No.	Burn Time, sec	Chamber Pressure, psia	LO_2 Flow, lb_m/sec	Fuel Flow, lb_m/sec	Seed[1] Flow, lb_m/sec	O/F	Cesium Content,[2] percent
77.1	5.7	233	3.21	0.70	0.0	4.6	0
78.2	5.2	249	2.91	0.97	0.46	3.0	6.2
78.3	7.3	219	2.66	0.83	0.43	3.2	6.4
79.1	6.1	244	2.69	0.97	0.58	2.8	7.8
79.2	4.6	264	3.10	1.07	0.13	2.8	1.8
79.3	5.0	273	3.18	1.14	0.50	2.8	5.9
79.4	7.6	240	2.81	1.11	0.0	2.5	0

[1]Seed Composition by Weight as Follows; 70 percent Cs_2CO_3, 30 percent H_2O

[2]Cesium Content Defined as Percentage of Cesium in the Total Flow

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13. ABSTRACT

A test program was conducted to determine the aerodynamic and thermal operating characteristics of a 45-deg slant-wall, magnetohydrodynamic generator channel under no-power conditions. The generator channel was 32.3 in. long with an inside diameter of 2.0 in. at the inlet, diverging to 4.9 in. at the channel exit. The plasma was provided by a liquid oxygen/JP-4 combustor having a nominal nozzle exit Mach number of 1.55. A solution of cesium carbonate dissolved in water was injected into the combustor to produce a high ion concentration in the exhaust stream. Nominal combustor operating conditions were as follows: chamber pressure, 220 to 275 psia; oxidizer-to-fuel ratio, 2.5 to 4.6; cesium concentration, 0.0 to 8 percent of total flow. Firing durations ranged from 4.6 to 7.6 sec. Tabulations of combustor operating conditions and a discussion of channel operating characteristics are presented.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
magnetohydrodynamics						
linear accelerators						
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conductivity						
electrical insulation						
combustion chambers						
liquid propellants						

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